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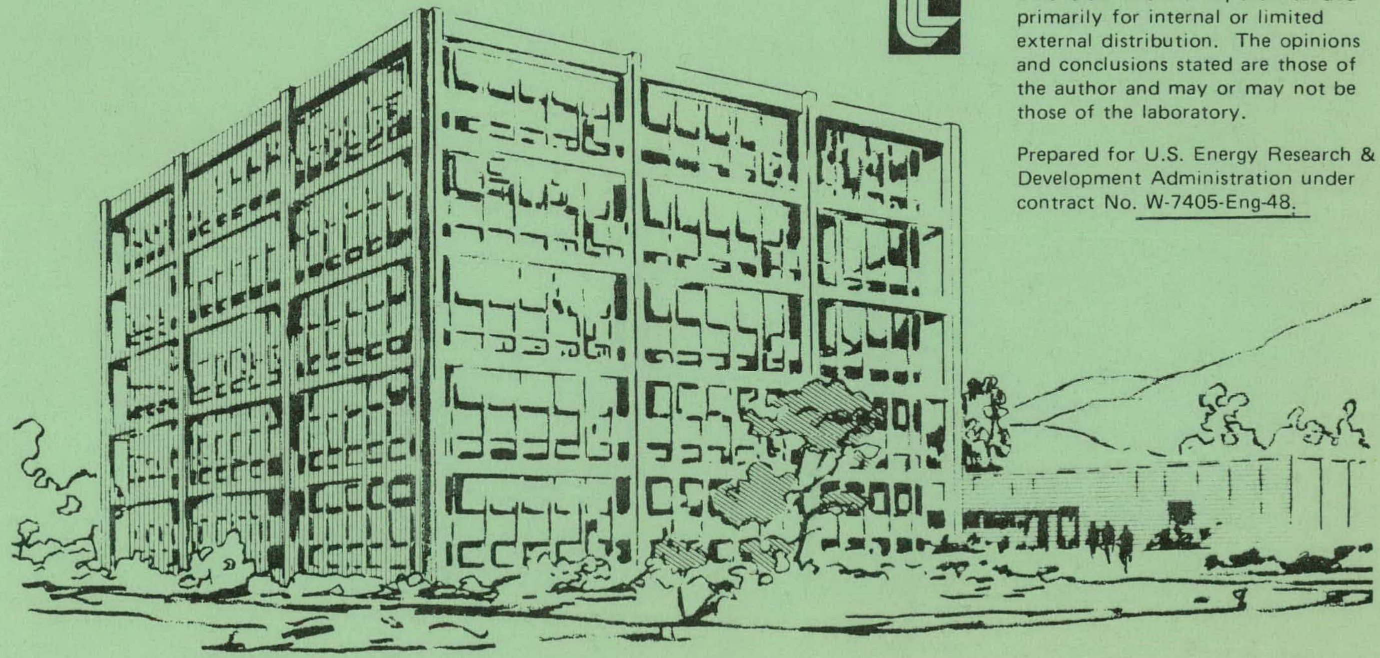
Investigation of the Thermal Yield from the Subsurface Explosions

Minao Kamegai

August 5, 1976



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Investigation of the Thermal Yield from the Subsurface Explosions

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ABSTRACT

The objective of this investigation is to determine the upper limits on the thermal yield of a 1 Kt source detonated at shallow depths. Three problems were computed for the depths of burial of 0.5, 1.5 and 3 m. The source is an iron bubble with 30 cm radius and 25 Kg of mass. The computation was done on the CEL code. The results show that the relative thermal yield is no more than 6%, and that it vanishes at DOB of about 4 m. The computed blast strength is plotted against the range. The results are consistent with the measurements on "Johnnie Boy" and "Jangle-U", and in good agreement with the RAD9 calculations and the HULL calculations.

Introduction

This report describes the results of a study on the thermal yield from the subsurface nuclear explosions. The objective of the investigation is to determine the upper limits on the thermal yield from a 1 Kt source detonated at shallow depths. The depths of burial (DOB) are 0.5, 1.5 and 3 m. The computation was done on a Coupled-Eulerian Lagrangian (CEL) code.[1,2]

An explosion in the free atmosphere loses as much as 30 to 40% of its energy by radiative processes such as x-ray emission and thermal pulse.[3,4] Of these processes, more than 95% of the radiative loss is due to thermal radiation. When the detonation takes place at shallow depths, the radiative process is inhibited by the optically opaque vaporized soil and other high Z materials. The thermal yield rapidly decreases with increasing depth of burial.

The peak over-pressure of the blast wave is plotted and compared with the other computations, the RAD9 calculation and the HULL calculation, and the measurements on "Johnnie Boy and Jangle-U". The CEL computation is consistent with the measurements. Within the computational error these three sets of ccalculations are mutually consistent.

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Computational Technique

The computation was done on CEL using the LLL equation of state and opacity tables.[5] CEL is a two-dimensional radiation - hydro code.[1,2] It calculates the equilibrium temperature with a diffusion equation. CEL couples the Eulerian and Lagrangian grids, utilizing the advantages of both schemes. The Lagrangian formalism is inherently more accurate than the Eulerian scheme for resolution of shock variables.[6] However, when there is a strong mixing of materials, the use of the Eulerian grid alleviates many computational difficulties. Therefore, CEL is most suitable where there is a strong interaction of gaseous materials with solids.

Using an iron bubble of 1 Kt energy as a source, the explosions at 0.5, 1.5 and 3 m were examined. Figure 1 shows the configuration of the problems. The atmosphere is represented by a Lagrangian grid because the accurate calculation of energy and other shock variables is required in this region. Since the ground motion is of little interest at this time, it is mapped in an Eulerian mesh. This alleviates computational difficulties at the expense of accuracy. The source is given by a Lagrangian grid so that an accurate account of the energy can be made. The source radius is 30 cm, and the total mass is 25 Kg. The tracer line is an air-soil interface.

These shallow explosions quickly communicate with the ground surface, and the source moves in an upward direction resulting in a "mushroom effect" (see Figure 2). The airblast appears as if it originated from a virtual point of explosion located at about 20 m above the ground surface. Because of this unique nature of the subsurface explosions, the center of the Lagrangian arcs describing the atmosphere is deliberately set at 20 m above the surface.

Results and Discussion

The radius of vaporization of soil plays an important role in the phenomenology of the subsurface explosions. The structure of the blast wave radically changes when DOB exceeds the radius of vaporization. This is easily understood when one examines the energy coupling to the atmosphere, which is shown in Figure 3. The radius of vaporization of soil is about 2 m for 1 Kt yield, and the coupling efficiency rapidly decreases as DOB exceeds the radius of vaporization. Figures 4, 5 and 6 clearly display the change in the structure of the blast waves. The debris boundary and the airblast for DOB = 3m appear very different from the others.

In Figures 4 (DOB = 0.5 m) and 5 (DOB = 1.5 m), the shape of the Lagrangian grid near the ground surface suggests a Mach stem. There is a strong turbulence behind the wave front near the ground, and three Mach waves are observed. The wave form in Figure 6 (DOB = 3 m) is much more spherical, and only a single shock propagates over the ground.

The hot source, which communicates with the ground surface, rapidly rises above the cold debris. A sphere of hot gas appears over a cone of the colder debris (see Figures 4 and 5). A sharp kink in the upper portion of the Lagrangian grid in Figures 4 and 5 is an intersection of two spherical waves. One wave is initially started by the rising ground, and the second wave is formed from the top of the debris when the hot gas has risen to the top.

Figures 7 and 8 are the vertical profiles of temperature and pressure, respectively, along the axis of symmetry. They clearly show that the hot gas is expanding over the colder rarefied gas.

The thermal radiation comes mainly from the upper portion of the debris. For DOB = 0.5 and 1.5 m, the source quickly penetrates the ground surface, and its temperature at venting is about 20 eV. The source at DOB of 3 m rises quite slowly near the center of the debris. Thus most of the radiative energy is absorbed by the cold materials. When the source finally rises above the debris, the temperature is down to a fraction of 1 eV. We examined the thermal energy of the debris, taking 0.25 eV to be the minimum temperature for the thermal spectrum.

The thermal flux depends on the temperature and the energy density of the materials. The energy density of the radiating source (the materials at temperatures greater than 0.25 eV) is plotted in Figures 9, 10 and 11.

The relative thermal yield has been measured for a number of atmospheric explosions.[7] The measured thermal yield vs the yield to mass ratio (the energy density) is plotted in Figure 12. Based on the measured thermal yield (Figure 12), the computed results shown in Figures 9, 10 and 11 give the upper limits on the relative thermal yields of the 1 Kt source for the three DOB's. The upper limits on the thermal yield thus obtained are plotted against the depth of burial in Figure 13.

There are only three points in Figure 13. Thus one can draw either a straight line averaging the three points or a dotted curve which follows the three points and approaches the value for a free field explosion at DOB = 0. The relative yield for the free field explosion of a 1 Kt source with the mass of 25 Kg is easily determined from Figure 12. It is about 15%.

If we take the straight line in Figure 13, it implies some interesting results. The relative thermal yield of the 1 Kt source (mass 25 Kg) exploded at shallow depths is no more than 6%. The thermal yield vanishes at the depth of burial of about 4 m.

When a Mach stem is formed, the shock pressure widely fluctuates near the ground surface. Above the Mach stem, the shock wave is a smoothly expanding spherical wave. Therefore, the peak overpressure of the blast wave was determined at 20 m above the ground surface and plotted against the range in Figure 14. The calculated overpressures are compared with the measurements on Johnnie Boy, Jangle-U, and the surface bursts.[8,9,10,11]

Johnnie Boy is a 1/2 Kt device detonated at 58 cm below the ground surface. The measured pressures are plotted against the scaled range in Figure 14. Jangle-U is a 1.2 Kt device detonated at 5.18 m below the surface. The computed results for DOB of 0.5, 1.5 and 3 m are consistent with these measurements

A blast wave for DOB = 3 m propagates smoothly over the ground surface. The peak overpressures near the ground surface (2 m above the surface) are plotted in Figure 15. They are compared with other calculations[12,13] and measurements. The three sets of computation done on CEL, RAD9, and HULL are in good agreement within the computational error.

Conclusion

We have conducted an investigation on the effects of the subsurface nuclear explosions, using the current computational technology. For the shallow depth explosions, the radius of vaporization of soil plays an important role. The thermal yield and the blast strength at high pressures become a strong function of DOB when DOB exceeds the radius of vaporization.

The thermal yield vanishes at DOB about twice the radius of vaporization. The yield to mass ratio as well as the temperature determines the thermal flux. Since the radiative mass of the debris is almost entirely the vaporized soil for a small device, the yield to mass ratio of the device itself has very little effect.

Although DOB can change the blast strength by orders of magnitude at high pressures, the peak overpressures at large distances, e.g., below 10 psi, are affected much less by DOB. The three sets of computations done on three different codes are mutually consistent within the computational error.

Closer attention should be given to the equation of state and the opacity because the radius of vaporization is very sensitive to the equation of state, and the opacity is a determining factor in energy transport. The current LLL tables for the equation of state and the opacity are not adequate in the region of our interest. More improvement is desired in this area.

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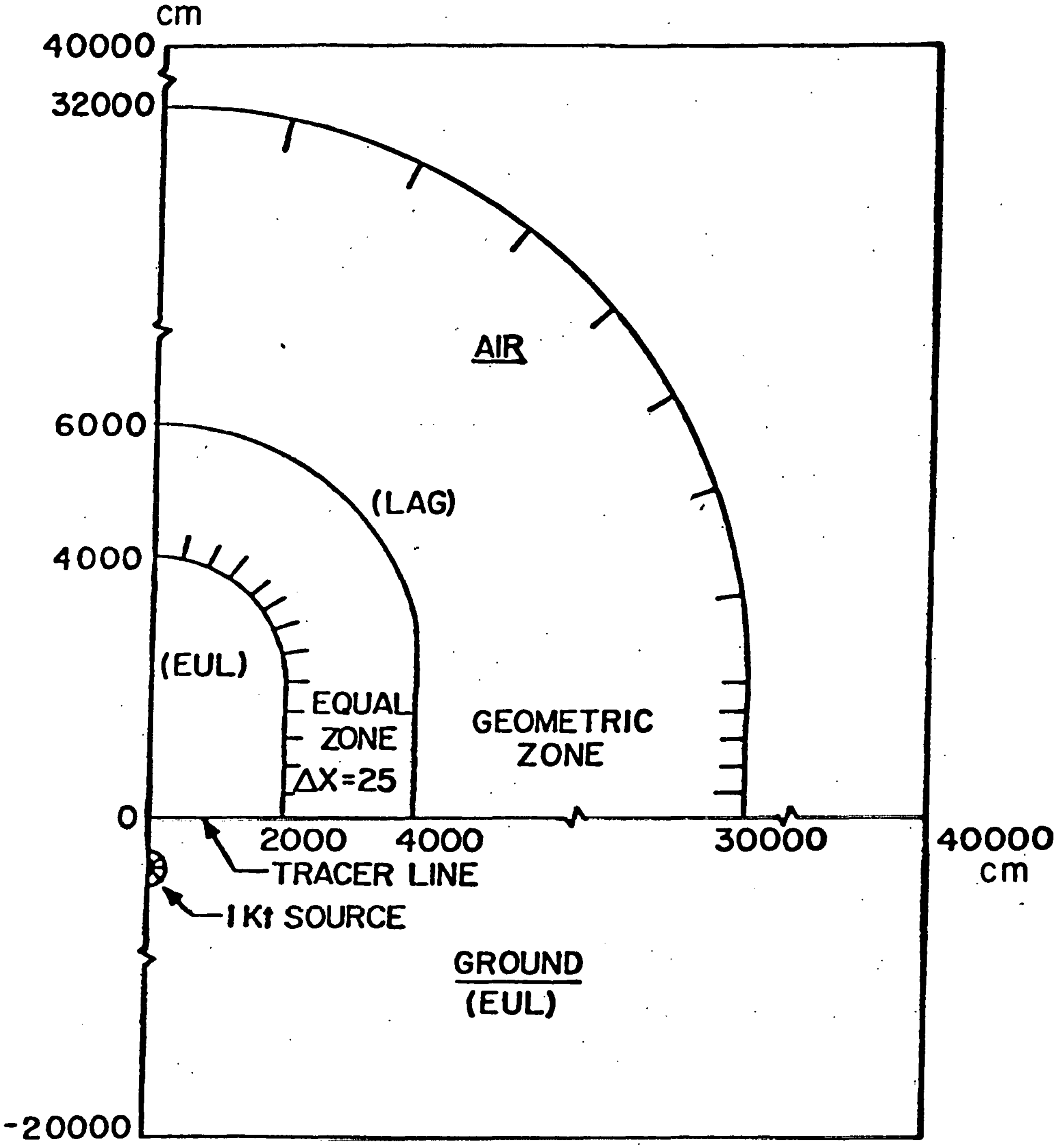
MK/gb

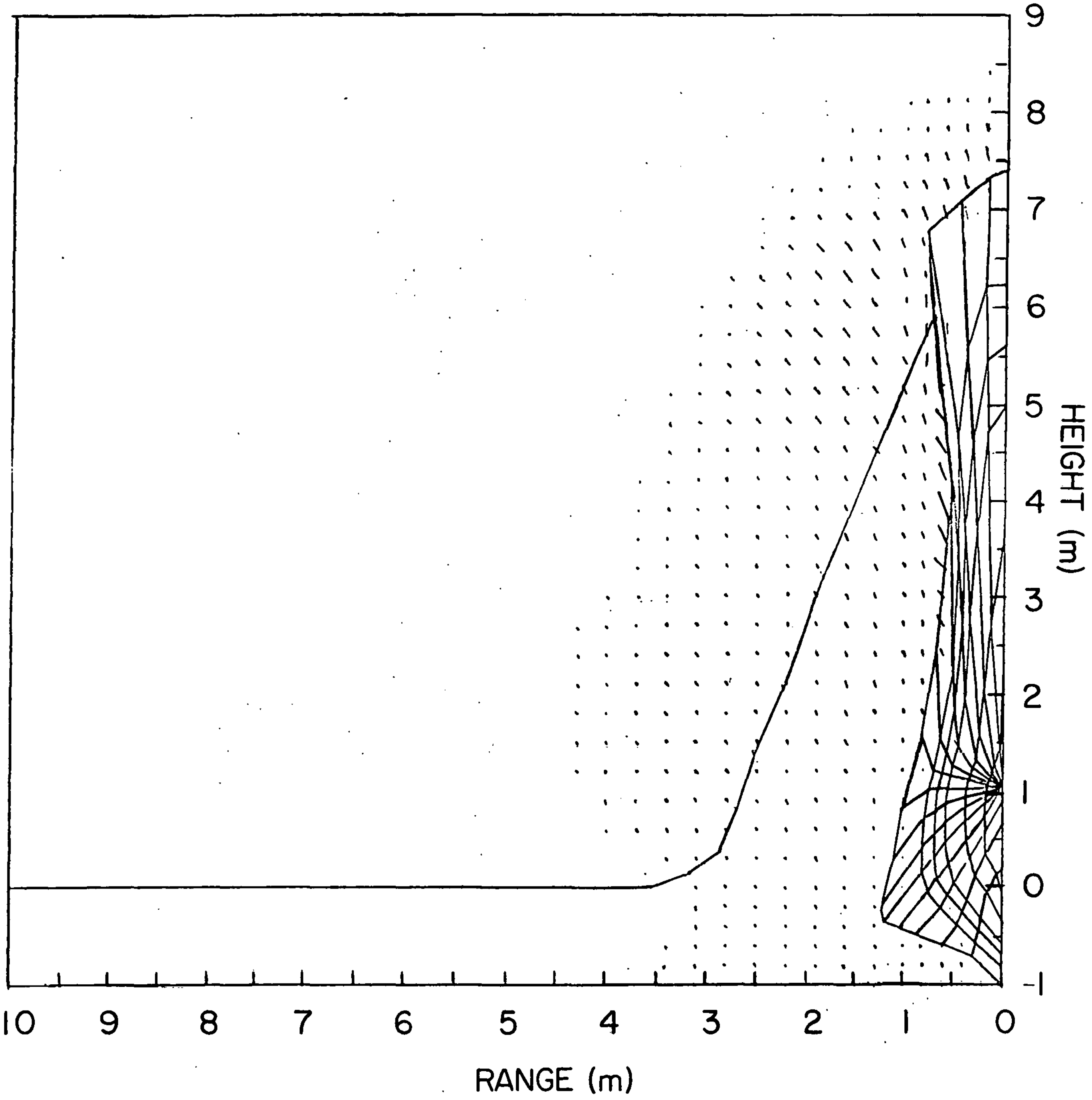
Figure Captions

Figure 1	Thermal Effects Study
Figure 2	Shallow Depth Explosion at 370 μsec, DOB = 1.5 m
Figure 3	Energy Coupled to the Air
Figure 4	Airblast at 9 msec, DOB = 0.5 m
Figure 5	Airblast at 10 m sec, DOB = 1.5 m
Figure 6	Airblast at 14.8 m sec, DOB = 3 m
Figure 7	Vertical Temperature Profile
Figure 8	Vertical Pressure Profile
Figure 9	Energy Density of the Radiating Source, DOB = 0.5 m
Figure 10	Energy Density of the Radiating Source, DOB = 1.5 m
Figure 11	Energy Density of the Radiating Source, DOB = 3 m
Figure 12	Relative Thermal Yield vs Yield to Debris Mass Ratio for Low Yield Devices
Figure 13	Relative Thermal Yield vs DOB
Figure 14	Comparison of CEL Calculations with Measurements
Figure 15	Blast Strength vs Range



THERMAL EFFECTS STUDY

Figure 1



370 μsec, DOB = 1.5 m

Figure 2

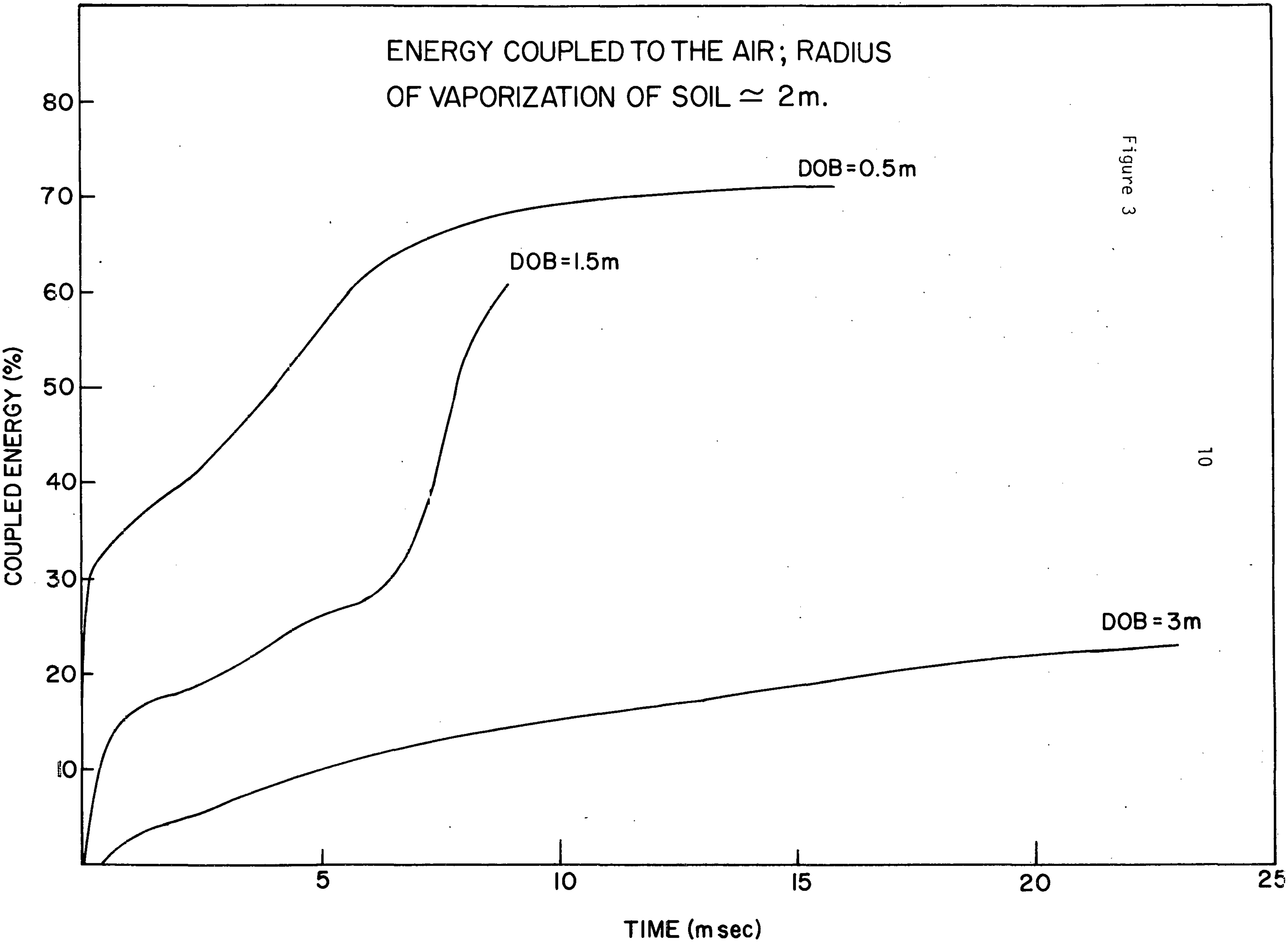
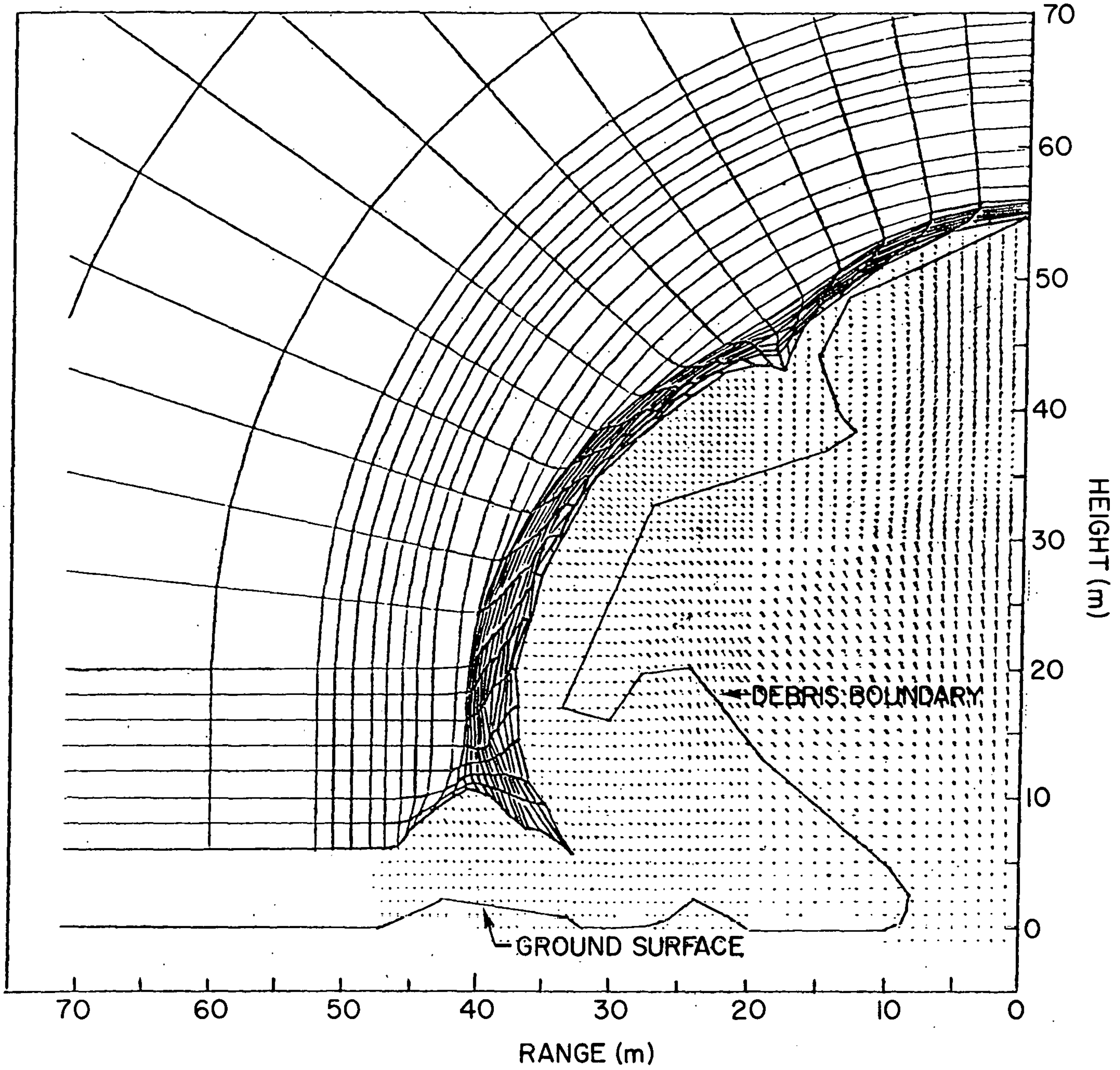

ENERGY COUPLED TO THE AIR; RADIUS
OF VAPORIZATION OF SOIL ≃ 2m.
DOB = 0.5m
DOB = 1.5m
DOB = 3m
COUPLED ENERGY (%)
80
70
60
50
40
30
20
10
TIME (m sec)
5
10
15
20
25

Figure 3



9 msec, DOB=0.5m

Figure 4

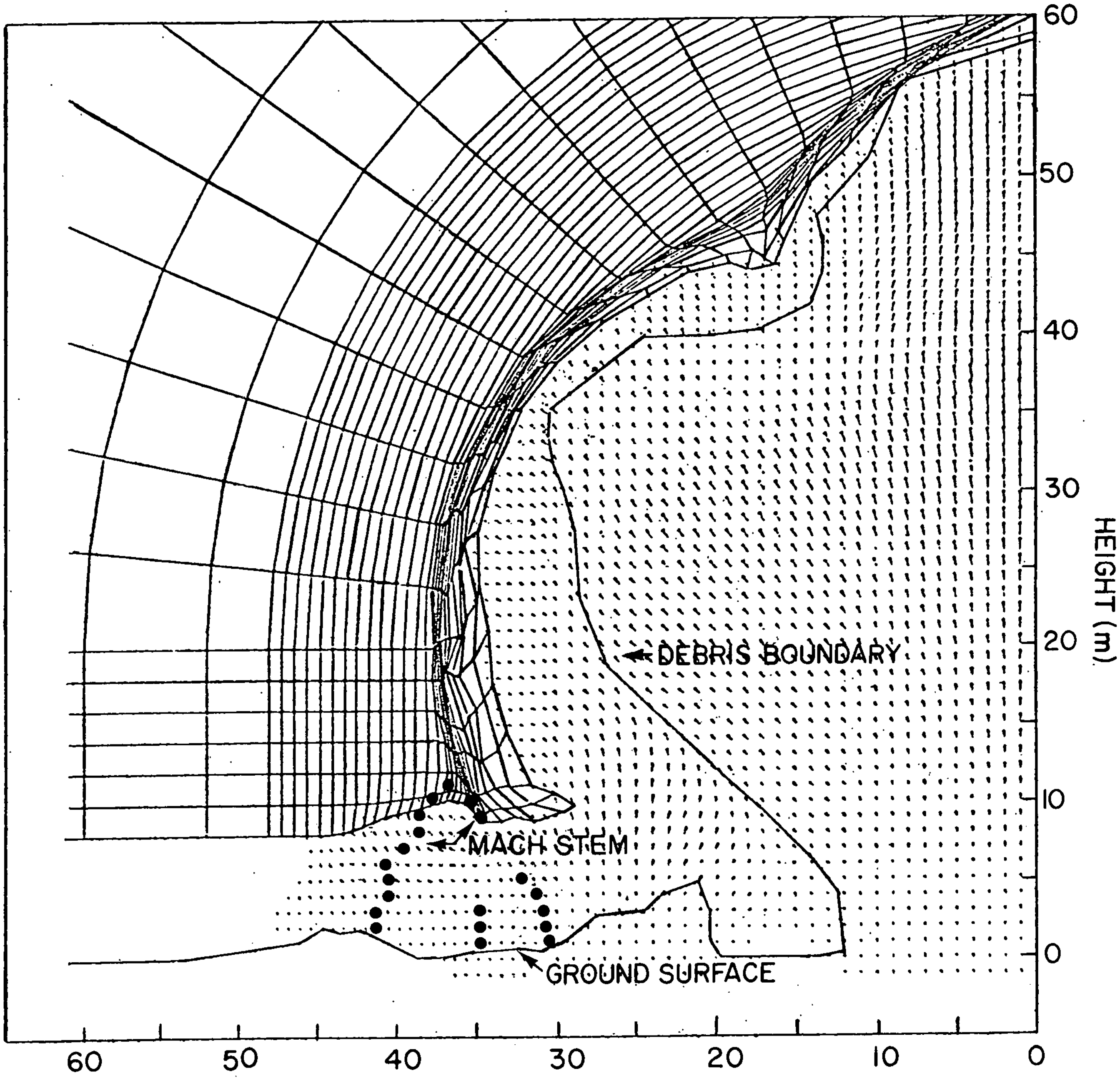

DEBRIS BOUNDARY
MACH STEM
GROUND SURFACE
HEIGHT (m)
60
50
40
30
20
10
0
RANGE (m)
60
50
40
30
20
10
0
10msec, DOB=1.5 m
● AIR SHOCK

Figure 5

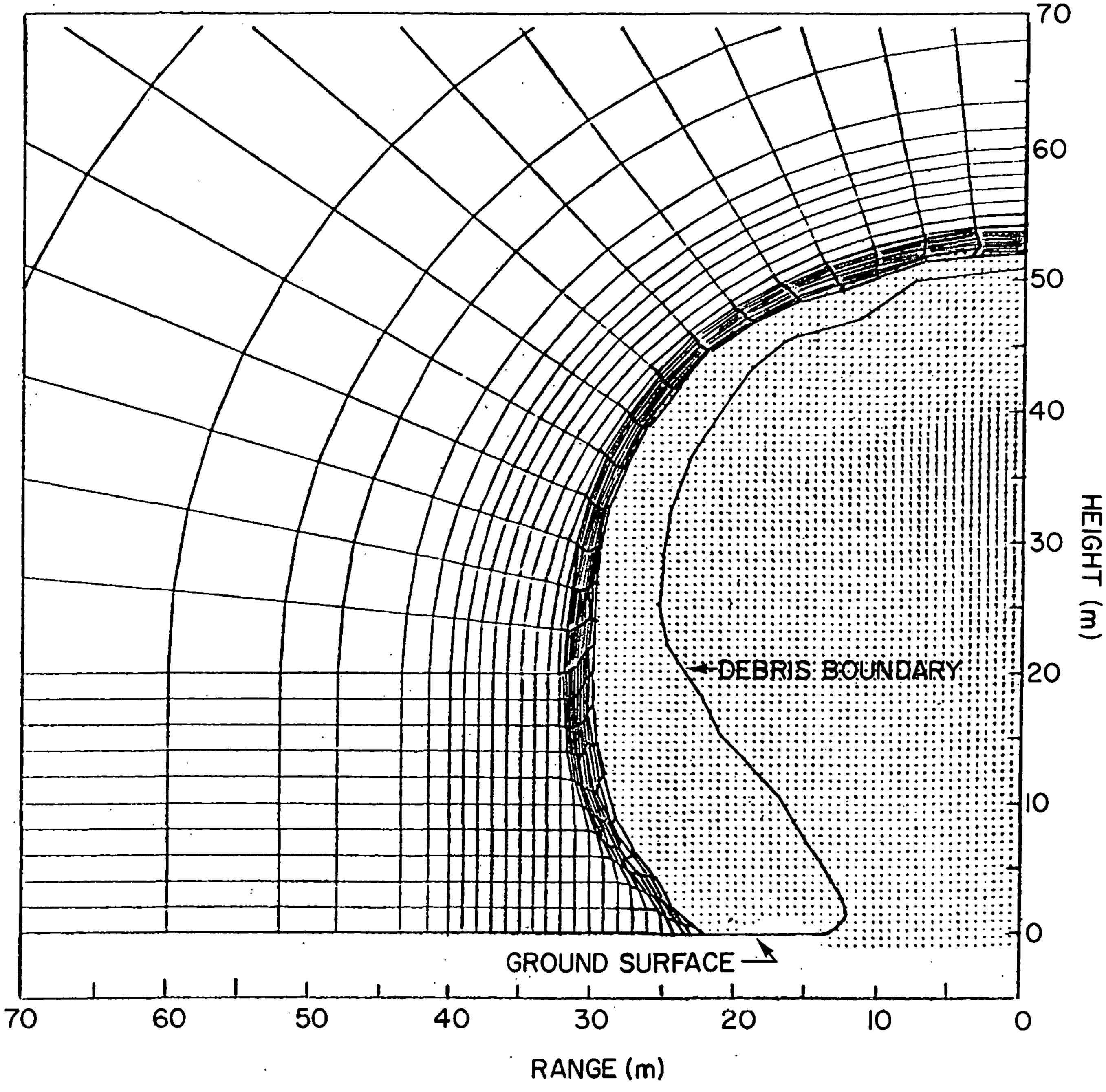

70
60
50
40
30
20
10
0
HEIGHT (m)
DEBRIS BOUNDARY
GROUND SURFACE
70
60
50
40
30
20
10
0
RANGE (m)
14.8msec, DOB= 3m

Figure 6

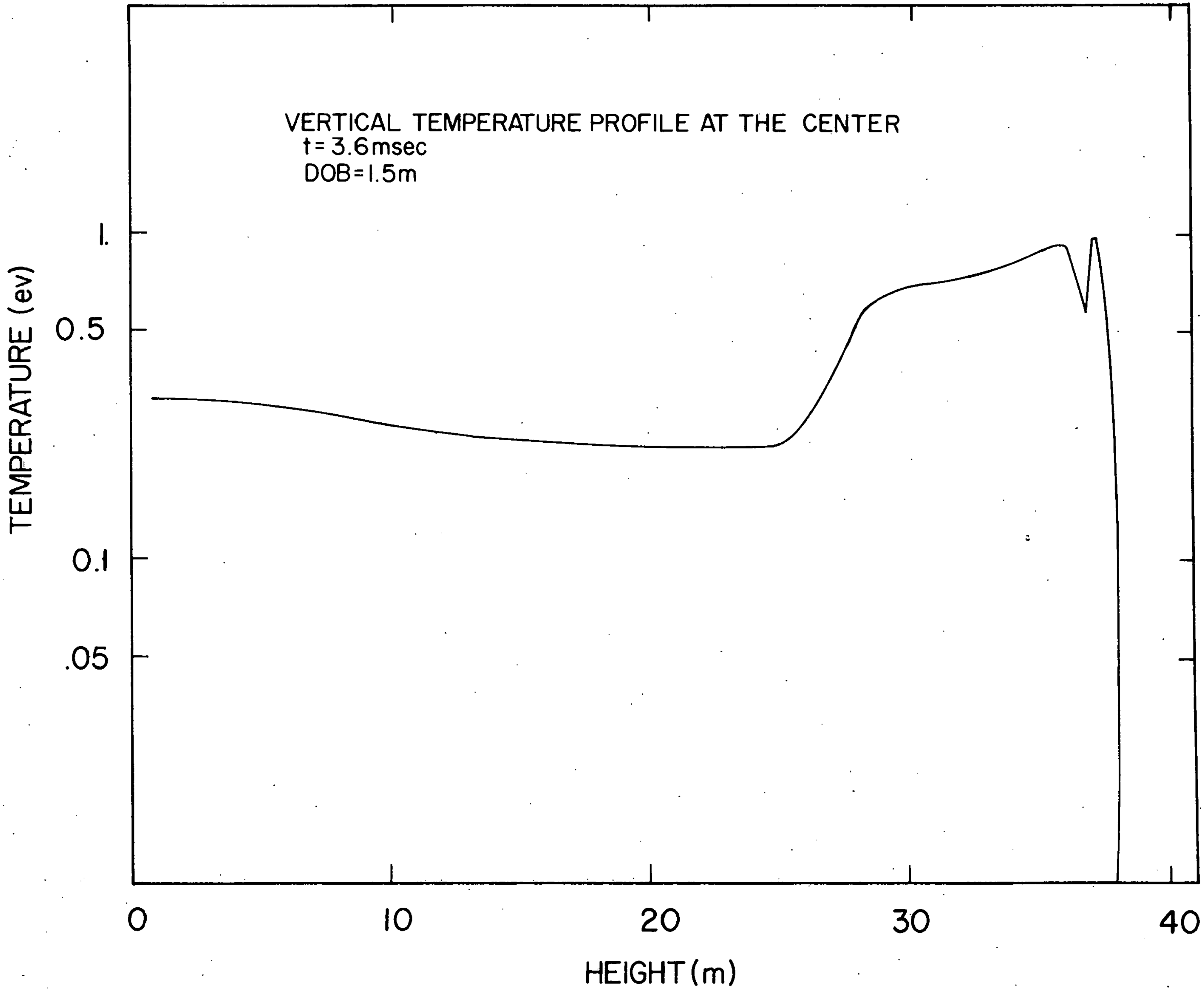

VERTICAL TEMPERATURE PROFILE AT THE CENTER
t = 3.6 msec
DOB = 1.5 m
TEMPERATURE (ev)
1.
0.5
0.1
.05
0
10
20
30
40
HEIGHT (m)

Figure 7

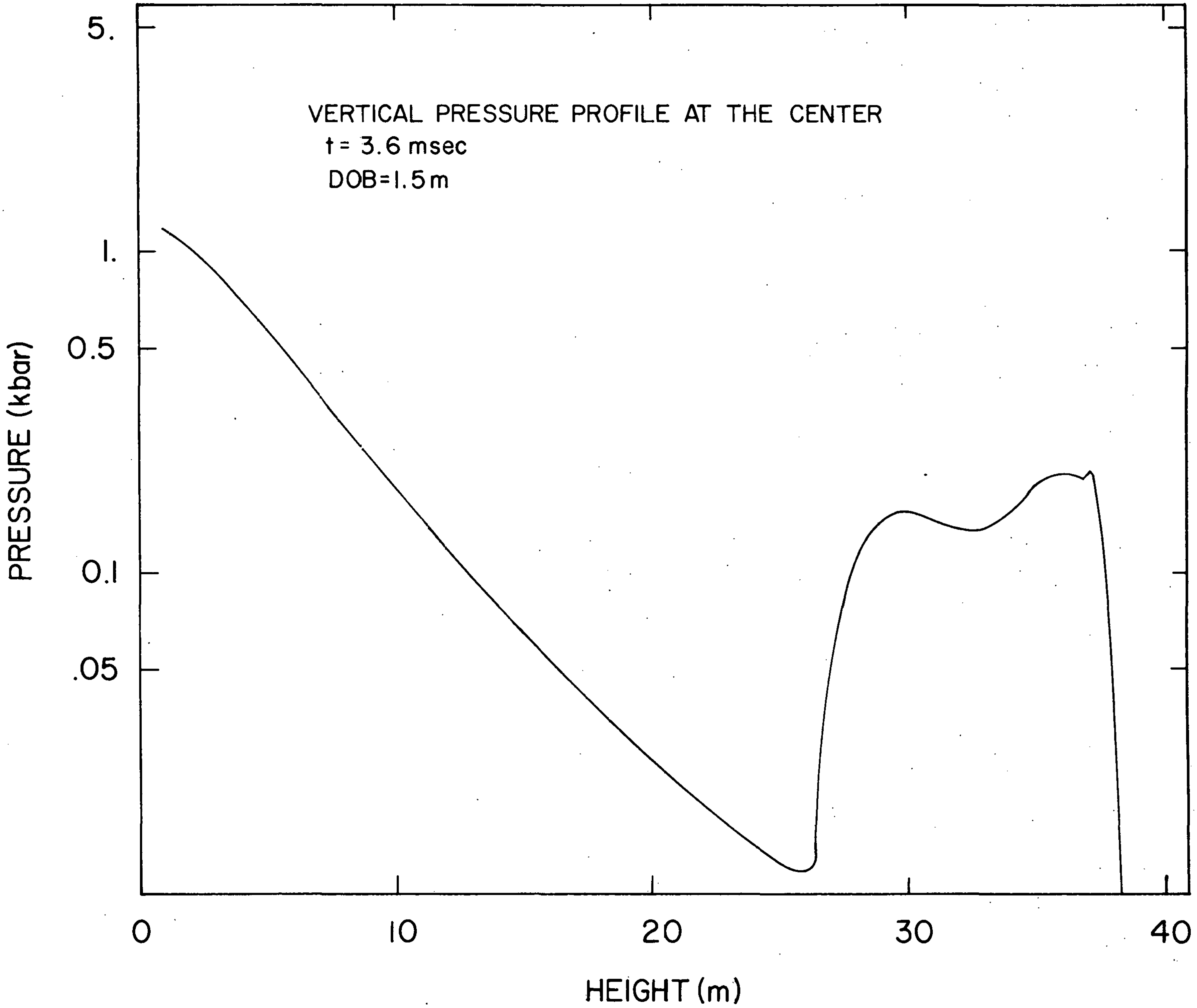

VERTICAL PRESSURE PROFILE AT THE CENTER
t = 3.6 msec
DOB=1.5 m
PRESSURE (kbar)
5.
1.
0.5
0.1
.05
HEIGHT (m)
0
10
20
30
40

Figure 8

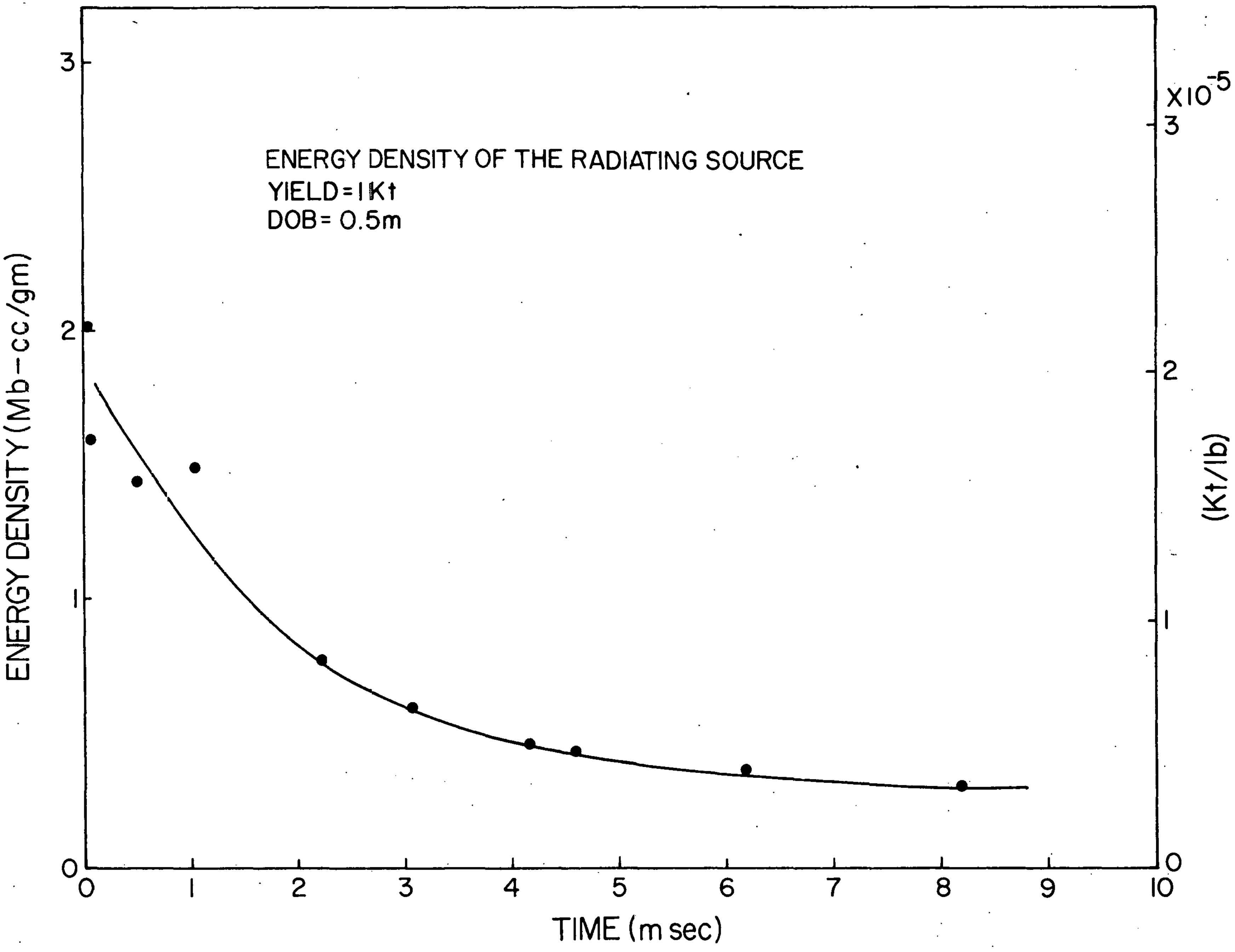

ENERGY DENSITY OF THE RADIATING SOURCE
YIELD = 1Kt
DOB = 0.5m
ENERGY DENSITY (Mb-cc/gm)
(Kt/lb)
X10^-5
TIME (m sec)
0
1
2
3
4
5
6
7
8
9
10

Figure 9

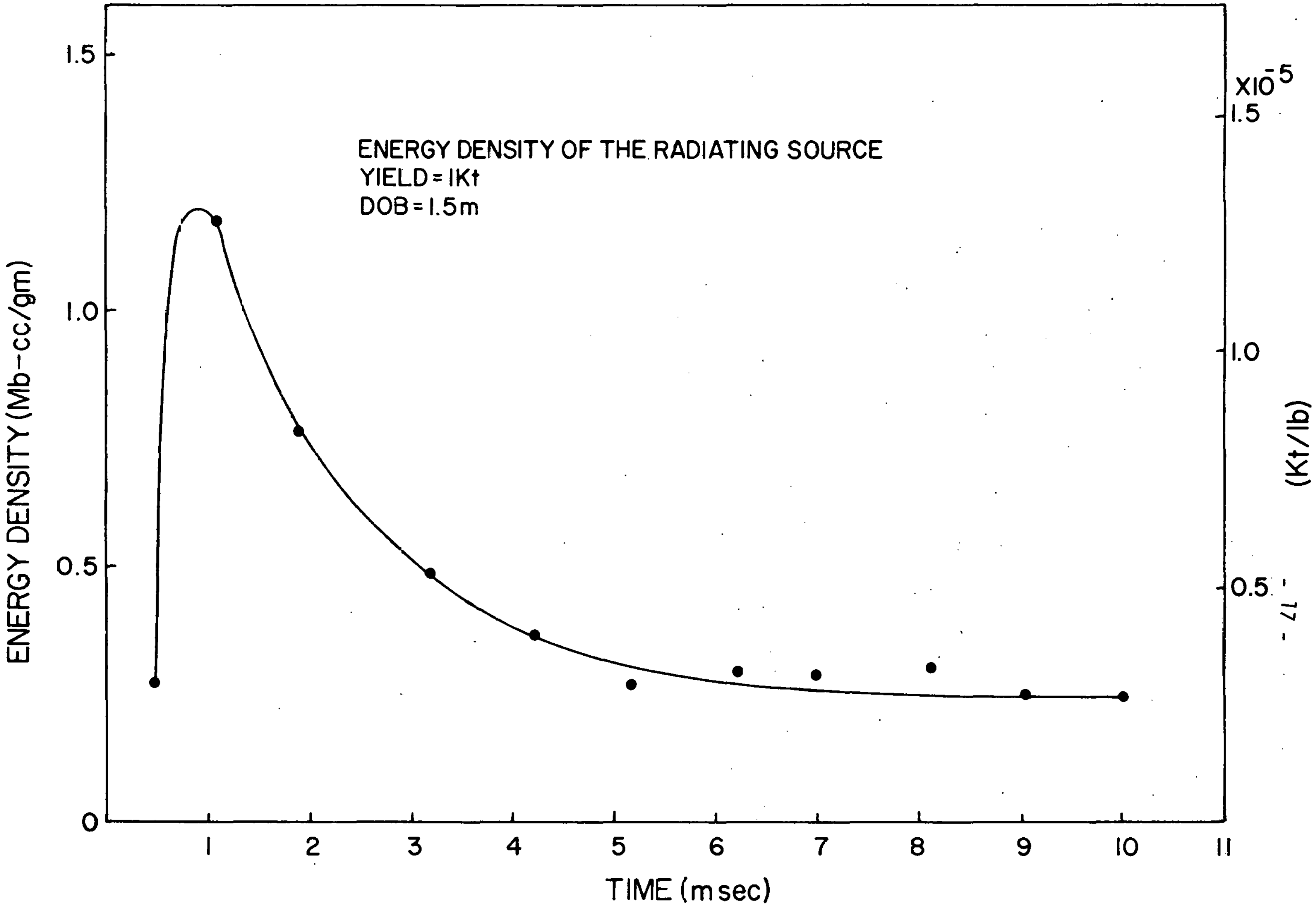

ENERGY DENSITY OF THE RADIATING SOURCE
YIELD = 1Kt
DOB = 1.5m
ENERGY DENSITY (Mb-cc/gm)
1.5
1.0
0.5
0
X10^-5
1.5
1.0
0.5
(Kt/lb)
1
2
3
4
5
6
7
8
9
10
11
TIME (m sec)

Figure 10

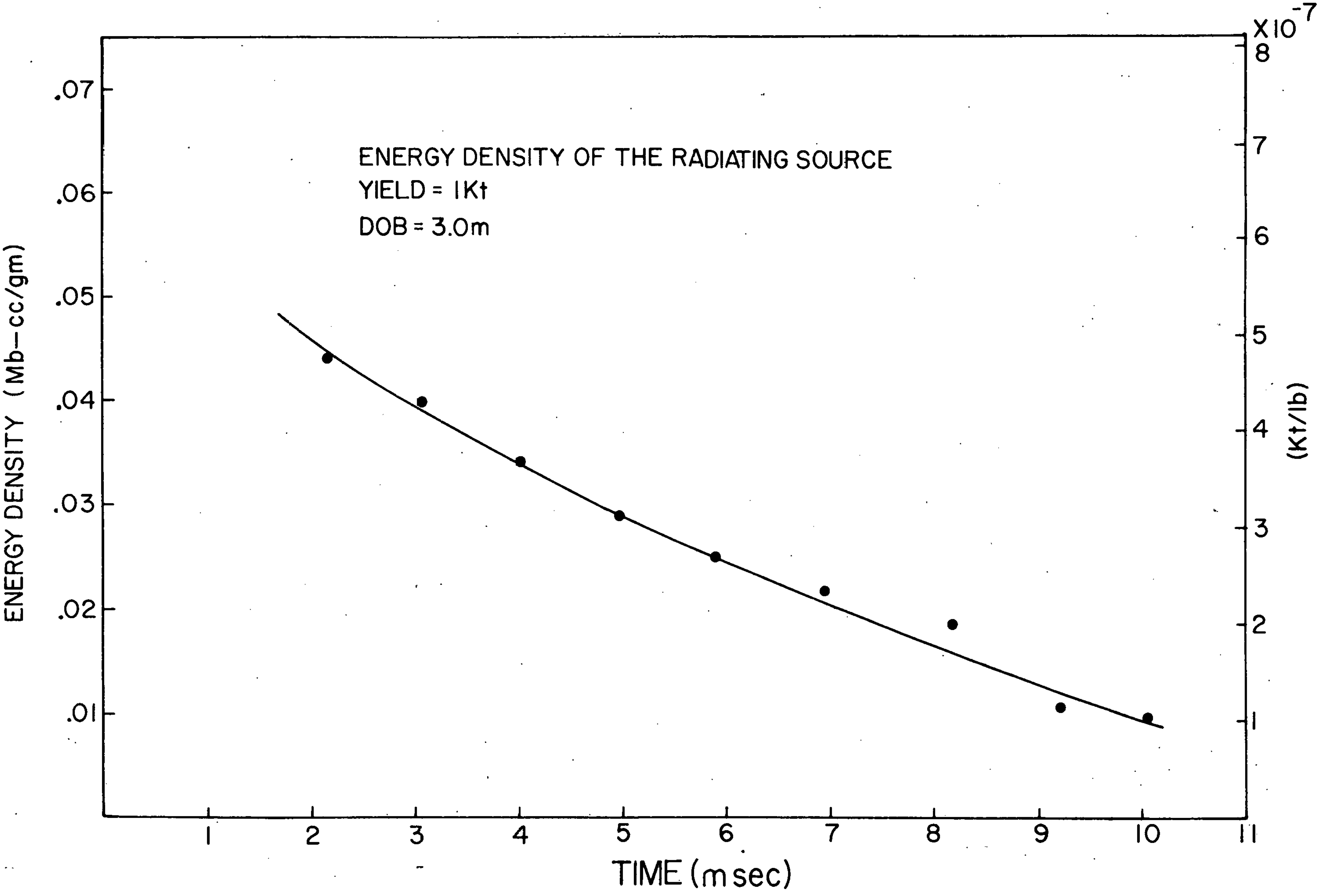

ENERGY DENSITY OF THE RADIATING SOURCE
YIELD = 1Kt
DOB = 3.0m
ENERGY DENSITY (Mb-cc/gm)
.07
.06
.05
.04
.03
.02
.01
X10^{-7}
8
7
6
5
4
3
2
1
(Kt/lb)
1
2
3
4
5
6
7
8
9
10
11
TIME (msec)

Figure 11

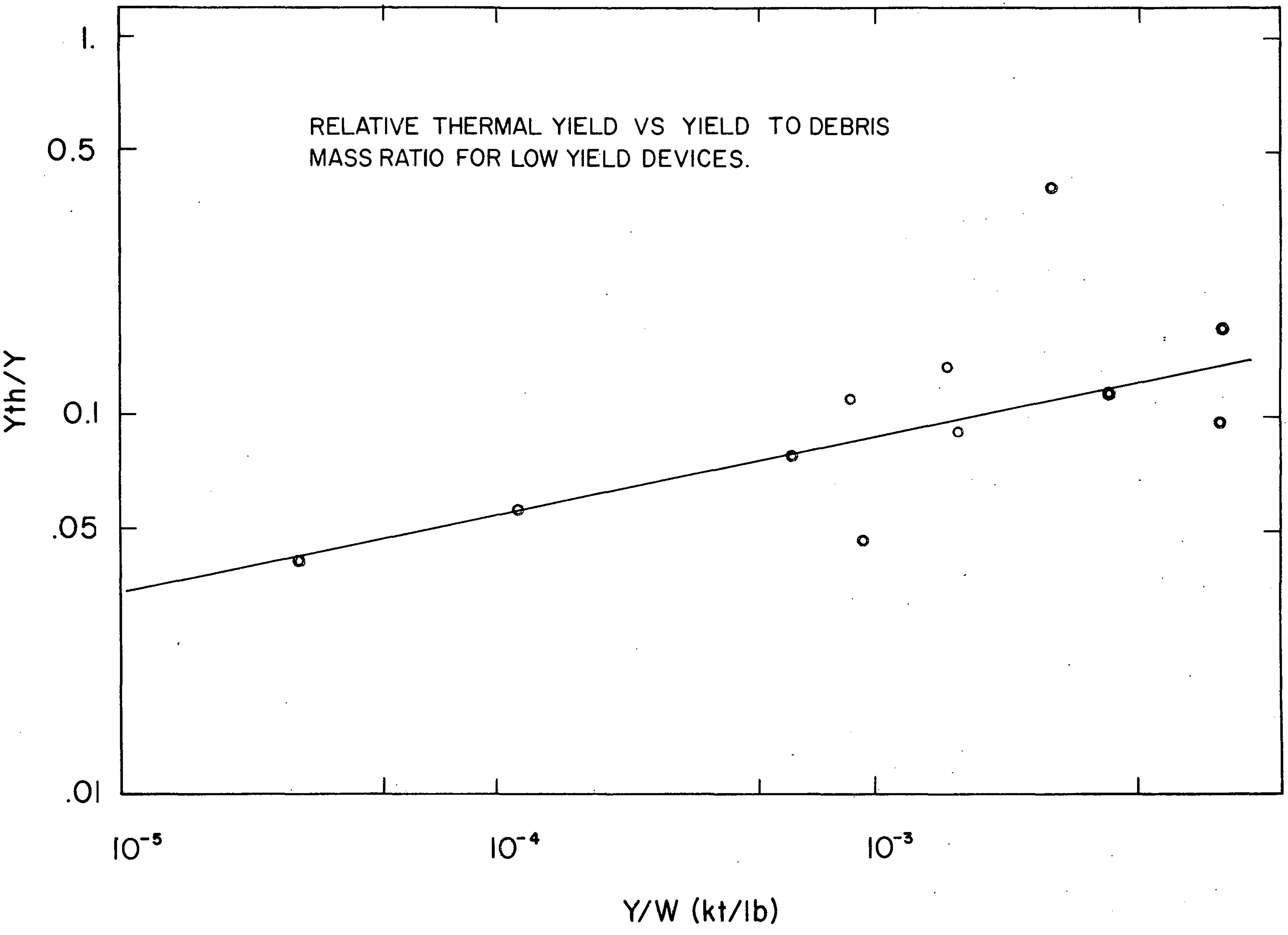

RELATIVE THERMAL YIELD VS YIELD TO DEBRIS MASS RATIO FOR LOW YIELD DEVICES.
1.
0.5
0.1
.05
.01
Yth/Y
10⁻⁵
10⁻⁴
10⁻³
Y/W (kt/lb)

Figure 12

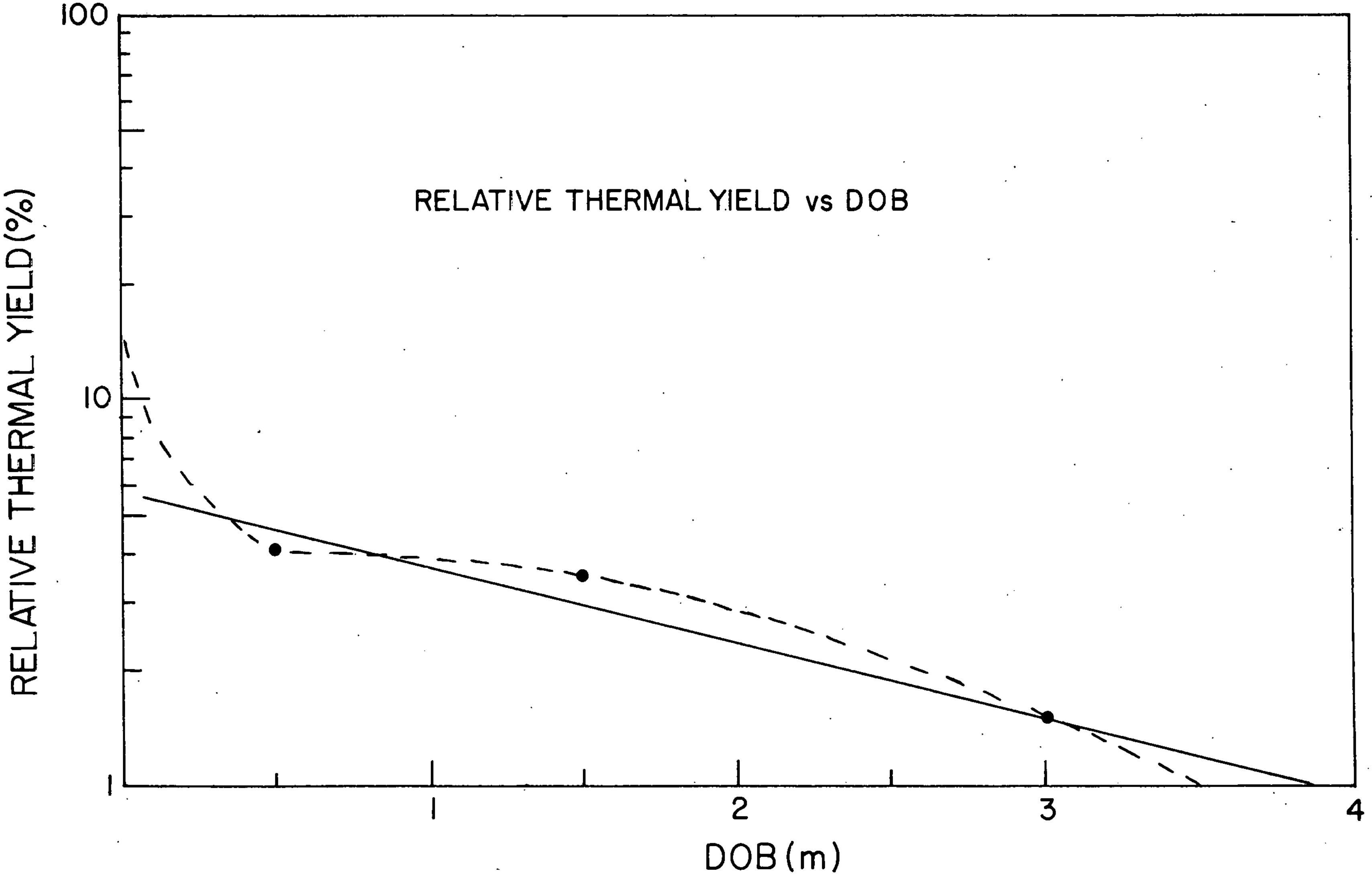

RELATIVE THERMAL YIELD vs DOB
RELATIVE THERMAL YIELD (%)
100
10
1
1
2
3
4
DOB (m)

Figure 13

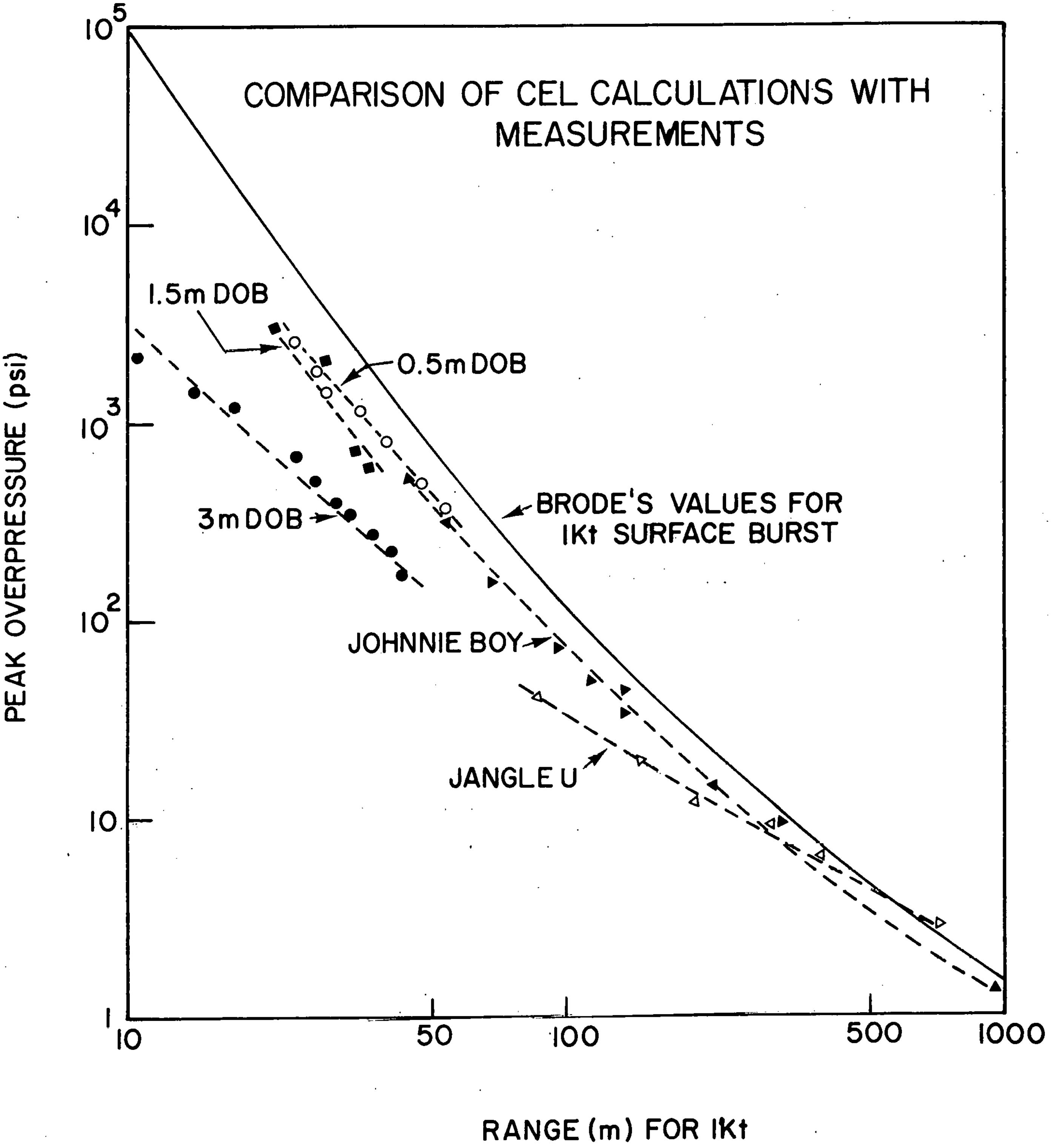

COMPARISON OF CEL CALCULATIONS WITH MEASUREMENTS
PEAK OVERPRESSURE (psi)
RANGE (m) FOR 1Kt
10^5
10^4
10^3
10^2
10.
1
10
50
100
500
1000
1.5m DOB
0.5m DOB
3m DOB
BRODE'S VALUES FOR 1Kt SURFACE BURST
JOHNNIE BOY
JANGLE U

Figure 14

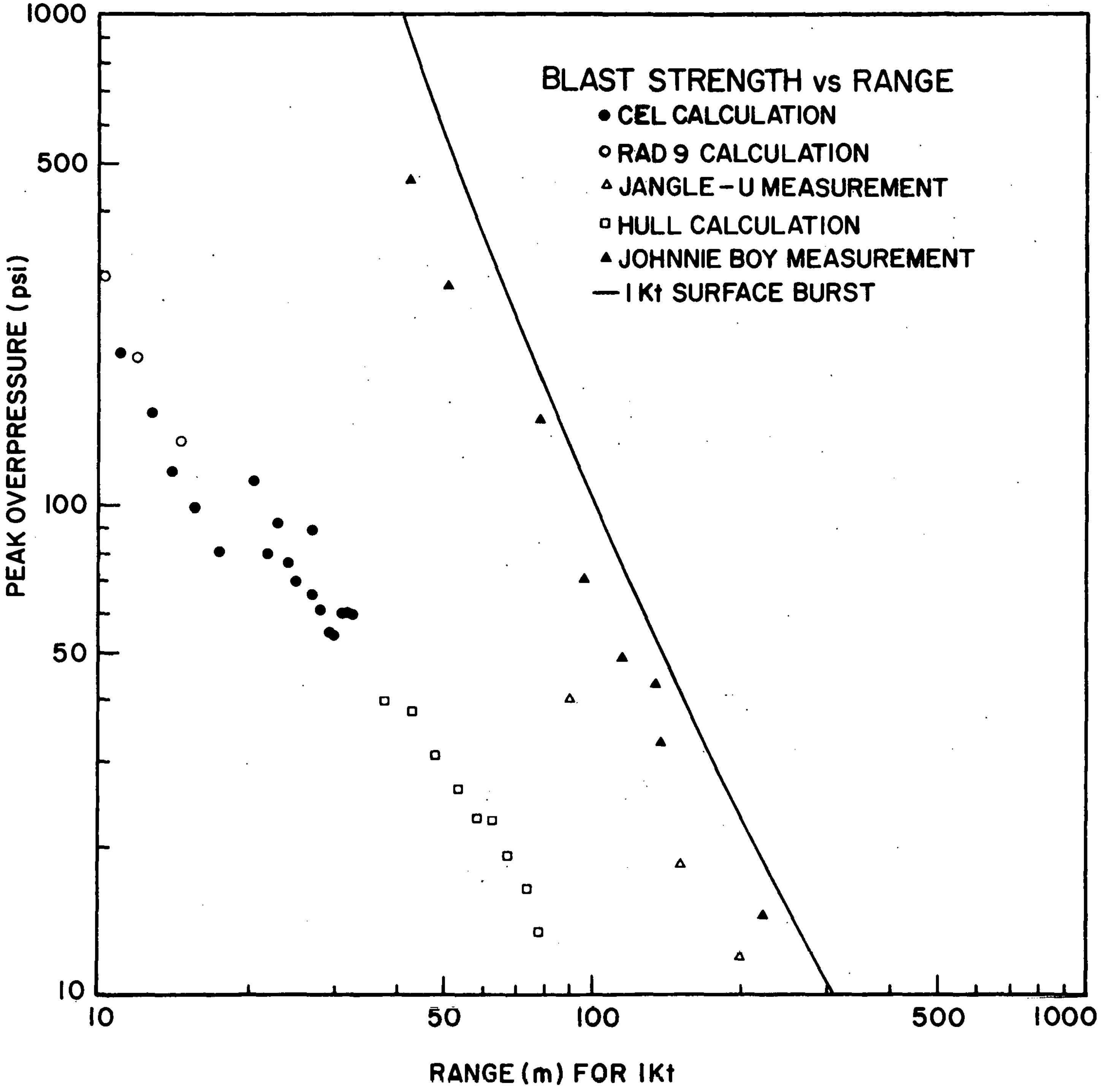

BLAST STRENGTH vs RANGE
● CEL CALCULATION
○ RAD 9 CALCULATION
△ JANGLE - U MEASUREMENT
□ HULL CALCULATION
▲ JOHNNIE BOY MEASUREMENT
— 1 Kt SURFACE BURST
PEAK OVERPRESSURE (psi)
1000
500
100
50
10
10
50
100
500
1000
RANGE (m) FOR 1Kt

Figure 15

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